Performance analysis of wireless RF communication relay channels over a sea environment in a geographical area of an archipelagos

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Abstract: It is widely known that the wireless communication between stations that exist and operate in a maritime environment has many factors to overcome in order to reach a certain high level of Quality of Service (QoS), especially when it has to do with military applications, such as the weather conditions, the distance between the stations e.t.c. Modern approaches for the solution of the abovementioned malfunctions are the use of satellites and the use of more than one receiving antennas. In this paper, the performance analysis of Single Input Single Output (SISO)and Single Input Multiple Output (SIMO)communication relay links will be investigated taking into consideration the interaction between the Bit Error Rate (BER), the Bit Rate and the Signal to Noise Ratio (SNR) for the type of multiplexing and modulation of the transmitted signal. The main objective is the need to mitigate the effect of the multipath propagation over the wireless wideband maritime communication channel. Moreover, in this work is examined the use of Unmanned Air Systems (UAS) as relay nodes in order to overcome possible obstacles that prevent the communication between stations and to extend the coverage of a communication link.

Keywords: Wideband maritime communication channel, SISO, SIMO, UAS, Multipath effect.

1. Introduction

Modern wireless RF communication networks are rapidly introduced in military operation theaters due to the advantages they offer, such as Line Of Sight (LOS), non-LOS connectivity and high speed secure data communications[1, 2, 3, 4, 5] . On the other hand, wireless RF systems suffer from various factors that degrade their performance. The main factor is multipath effect, where the information signal arrives at the receiver many times but in different time slots following different trajectories due to reflections or refractions in the troposphere. Furthermore, the presence of obstacles, inside the Fresnel Zone, between the transmitter and the receiver, is responsible for performance deterioration of the communication system [3, 6, 7, 8, 9, 10, 11].

In order to increase the performance of the communication systems, various techniques have been proposed. The most effective is the use of multiple antennas at the receiver (SIMO) or the transmitter (Multiple Input Single Output, MISO) due to differential reception [12, 13, 14, 15]. Another technique used to avoid obstacles, is multihop communications, where transceiver nodes are placed between the transmitter and the receiver [11,16, 17, 18].

In this work, the reliability of a multihop SIMO system will be investigated under multipath effect and it will be estimated using the Rayleigh distribution. It is well known that using the Rayleigh distribution is achieved to create a model of the communication scheme when the signal is scattered from particles that exist in the environment (such as the sea waves) [9, 19]. In addition to this, due to the fact that the Rayleigh distribution describes fast fading statistics in the region of troposphere scattering waves, therefore it is more useful for communication during military operations. The communication system will imply the Orthogonal Frequency Division Multiplex (OFDM) which is an effective technique for broadband communication schemes and every subcarrier will be modulated using Quadrature Amplitude Modulation (QAM) [9, 20, 21, 22]. The metric that will be investigated, is the BER which is very important, as it indicates the reliability of the system. For Frequency Hopping (FH) a mechanism must be designed so that the data can be transmitted in a clear channel and avoid channel congestion [23, 24, 25, 26]. Compared to a narrowband signal, Spread Spectrum (SS) spreads the signal power over a wideband and the overall SNR is improved because only a small part of the signal is affected by interference. In a communication system, in both transmitter and receiver sides, one spreading generator has been located which, based on the spreading technique, they synchronize the received modulated spectrum. Employing the FHSS technology privacy, QoS is improved as it is difficult for the signal to be intercepted, the interference and multipath fading (distortion) is decreased whereas the signal capacity is increased, the SNR is improved, the efficiency of bandwidth is high and finally, this transmission can share a frequency band with many types of conventional transmissions with minimal interference.

2. System Model

The system consists of two warships that, due to obstacle between them that makes direct communication impossible, may communicate using a UAS creating a dual hop system. The UAS is assumed to be a Decode and Forward relay (DF) node, as it receives the direct and the overheard signals from the transmitter, it decodes them and then forwards them to the receiver.

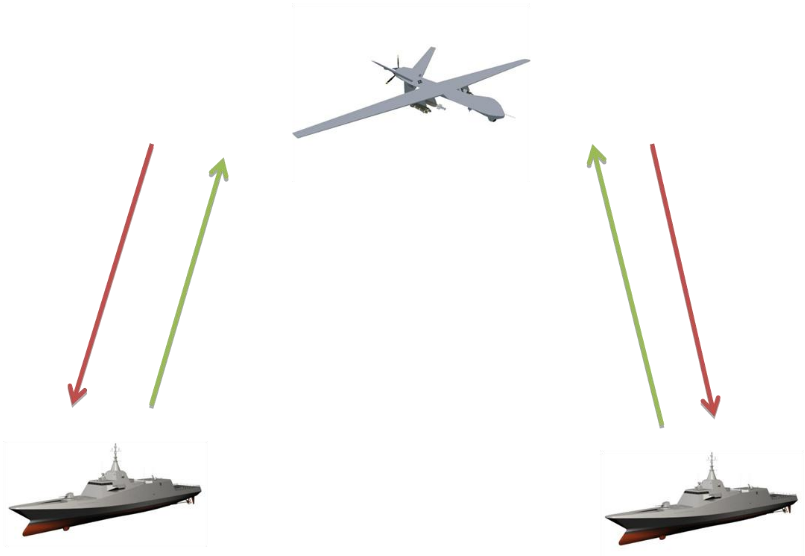

Fig. 1: UAS as relay communication node.

However the presence of this obstacle may still affect the performance of the system creating multipath effect. This effect can be investigated using various statistical distributions. In this work the Rayleigh distribution is employed since there is no dominant propagation along a LOS between the transmitter and receiver. The Probability Density Function (PDF) is given by the following equation [9, 19]:

$$P(\gamma)=\begin{cases}\dfrac{\gamma}{\sigma^2}e^{-\frac{\gamma^2}{2\sigma^2}}, & \gamma>0\\ 0, & \gamma\le 0\end{cases} \tag{1}$$

where γ is the envelope amplitude of the received signal and σis the standard deviation[8]. Furthermore, the system is assumed to employ the OFDM technique in order to eliminate the intersymbol interference (ISI), a very important factor that degrades the performance of an RF system. In OFDM, the transmitted signal will be given by the following equation [3, 9, 21, 22]:

$$x_l(t)=\sum_{k=\frac{N_s}{2}}^{\frac{N_s}{2}-l} S_{l,k}\,g(t-((i+1)T_s))\exp(j2\pi f_k t) \tag{2}$$

where N_s is the length of the block that $S_{l,k}$ complex symbols create, T_s is the period of one symbol and f_k is the frequency of the *k*th subcarrier.

Every subcarrier of the OFDM transmitted signal will be modulated using the QAM technique and the result will be given by the following equation [3, 9, 21, 22]:

$$s_m(t)=Am_i g(t)\cos 2\pi f_c t - Am_q g(t)\sin 2\pi f_c t, m=1,2,...,\mathrm{M} \tag{3}$$

Moreover, in order to avoid greater obstacles, such as islets, and therefore extend the communication range between the transmitter and the receiver, the multihop technique can be applied using multiple UAS as DF relay nodes, where N is the number of the UAS employed. In this case the final structure is (Fig. 2):

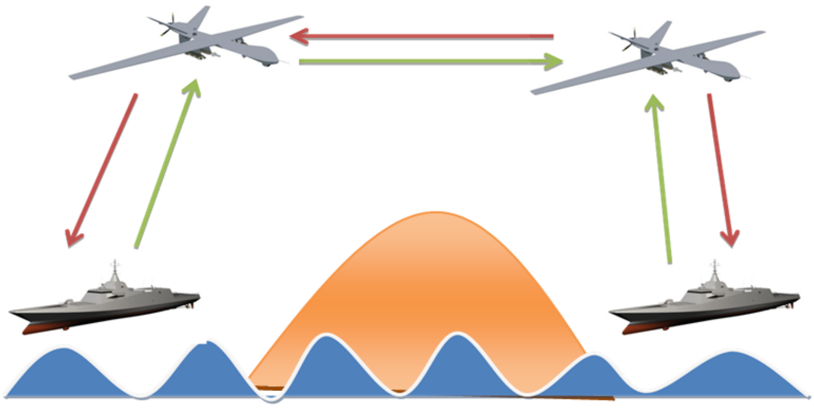

Fig. 2: UAS as relay DF node.

A cooperative multihop communications scheme is described in Fig.3:

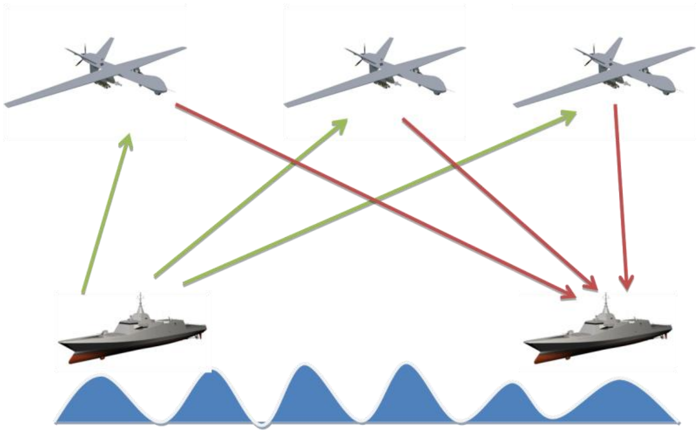

Fig. 3: Cooperative multihop communication scheme using 3 UAS as relay DF nodes.

The transmitter using N UAS as independent transponders, ensures that the receiver will get good signal quality, at least through one of the UAS. Moreover, this scheme works complementarily, as if one of the UAS gets destroyed or intercepted, the communication between the two warships will not break down. On the other hand, the receiver has to process all N received signals in order to obtain the information sent either by the cancelation or the superposition of the N received messages.

Instead of the simple SIMO technique, cooperative multihop scheme may be used, because in the simple multihop technique obstacles may be avoided, but degradation of the quality of the received signal, caused by the hops from UAS to UAS will be observed. Moreover, the more the nodes used, the better the system performance achieved, as long as, for a specific value of SNR, the BER decreases as the number of UAS increases.

Using the FHSS technique, the frequency of the carrier gets changed under a certain rate. Furthermore, Adaptive Frequency Hopping is implemented against frequency interference by avoiding congested frequency channels to be used in hopping sequence.

FH occurs over a frequency bandwidth covering numerous channels and is categorized into slow hopping and fast hopping. During slow hopping, more than one data symbol is transmitted in the same channel, whereas in the case of fast hopping, frequency changes several times per symbol. The hopping spectrum is called total hopping bandwidth. To generate a hopping sequence number as the channel number, that uplink "receiver" sends this number as feedback to downlink "transmitter", which can be shown in a linear equation [13] and assuming binary transmission the capacity of the feedback block is [23, 24, 26]:

$$C_f = N_a \log_2 N + C_{OH} + R_x \qquad (4)$$

where N is the total available channels, N_a are the active channels, C_f are the chips on feedback, C_{OH} is the feedback overhead and R is the chip rate.

A general model of SS digital communication system can be seen in the following Fig:

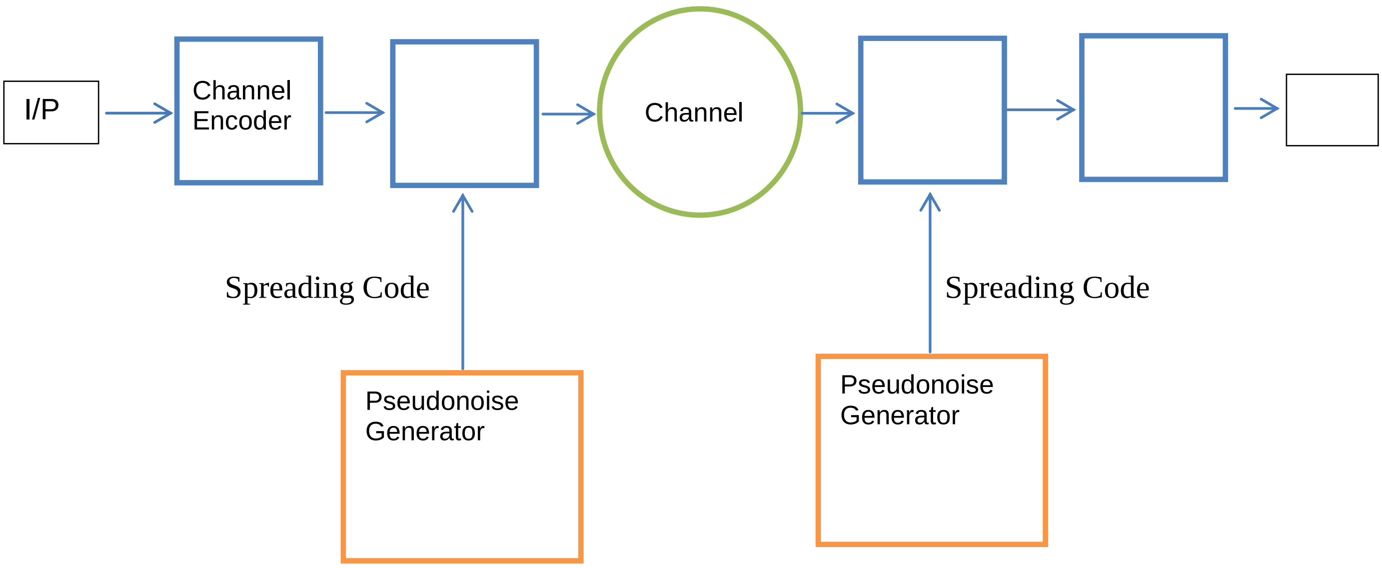

Fig. 4: A general model of SS digital communication system.

Taking advantage of all the above characteristics of the communications system proposed, we can proceed to the analysis of a SIMO system [15]. In a SIMO spatial divert system, one transmitter will send data to a number of receivers that present total aperture surface equal to the receiver of the SISO occasion.

3. Performance of multihop SISO system

Taking the *k*-th subband of the M-QAM modulation using the Rayleigh distribution, the BER of the Symbol Error Rate (SER) is given by [21, 27]:

$$\mathrm{P} = \int_0^\infty \{1-[1-\frac{2(\sqrt{M}-1)}{\sqrt{M}}Q(\sqrt{2\gamma})]^2\}\,\mathrm{p}(\gamma)d\gamma, \tag{5}$$

where Q(x) is the Gaussian tail function and γ is the SNR. Then, using equations (1) to (3) we can compute the BER of M-ary QAM in Rayleigh channel which is:

$$P_k = \prod_{k=1}^{N}\{\frac{M-1}{M\log_2 M}\left[1-\sqrt{\frac{(3\gamma_k \log_2 M)/(\mathrm{M}^2-1)}{[(3\gamma_k \log_2 M)/(\mathrm{M}^2-1)]+1}}\right]\} = \prod_{k=1}^{N} P_e(SISO) \tag{6}$$

In case N-UAS are employed as relay nodes, the BER can be calculated using the following equation [11, 17, 18] :

$$P_H = \sum_{i=1}^{H}[P(\mathrm{i})\prod_{j=i+1}^{H}(1-2\,\mathrm{P(j)})\,, \tag{7}$$

where H is the number of the hops.

4. SIMO systems

A SIMO system is a spatial diversity technique where the signal is transmitted from a single transmitter to multiple (N) receivers. In this case, the probability of error will be given as [21]:

$$P_s = Q(\sum_{k=1}^{N}\sqrt{2\gamma_k})]\ . \tag{8}$$

So the BER will be given by:

$$\mathrm{P}_k = \int_0^\infty \{1-[1-\frac{2(\sqrt{M}-1)}{\sqrt{M}}Q(\sum_{k=1}^{N}\sqrt{2\gamma_k})]^2\}\,\mathrm{p}(\gamma_k)d\gamma_k \tag{9}$$

Finally, executing the integral of equation (9) and applying

$$Q(x) = \frac{1}{2} e^{-\frac{x^2}{2}} \tag{10}$$

equation (9), results in

$$P_k = \prod_{k=1}^{N} \{ \frac{M-1}{M \log_2 M} \left[1 - \sqrt{\frac{(3\gamma_k \log_2 M)/(\mathrm{M}^2-1)}{[(3\gamma_k \log_2 M)/(\mathrm{M}^2-1)]+1}} \right] \} = \prod_{k=1}^{N} P_e(SISO) . \tag{11}$$

5. Numerical Results

In this section the numerical results of the Multihop OFDM QAM system are presented.

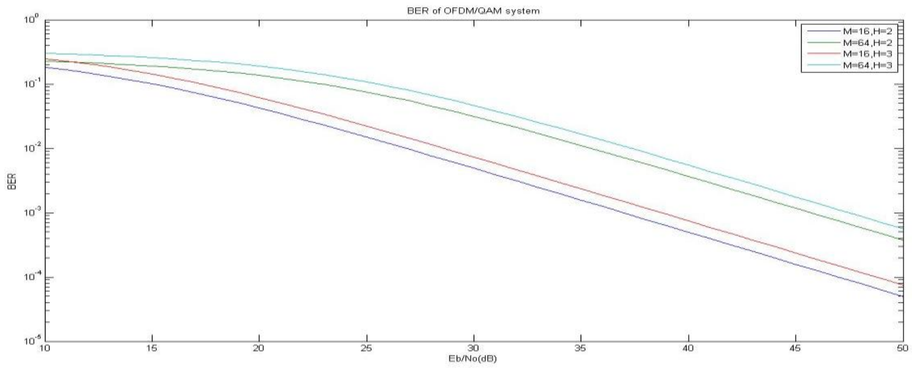

Fig 5: BER-Eb/No of OFDM/QAM SISO system.

In Fig. 5 a 16-QAM and a 64-QAM OFDM system are compared in terms of BER and Eb/No (SNR),where Eb is the energy per bit of the signal and No is the power of the noise . As it can be derived from Fig. 5,for both systems, as SNR increases, BER decreases and the system shows better performance, but needs more power to operate. In addition to this, for a certain value of SNR (i.e. 30 dB), as M increases, BER increases too and the system is less efficient. Moreover, as M increases the performance of the system deteriorates because the Euclidian distance between the points of the modulation constellation is more dense and there is high probability of error during the transmission.

Another aspect examined, is the number of UAS used. In dual-hop systems, (H=2) one UAS is used whereas in multihop systems two or more UAS are employed (e.g. H=3). It is obvious that the more the hops deployed, the higher the BER is, but longer distances of communication between the transmitter and the receiver can be achieved (beyond LOS).

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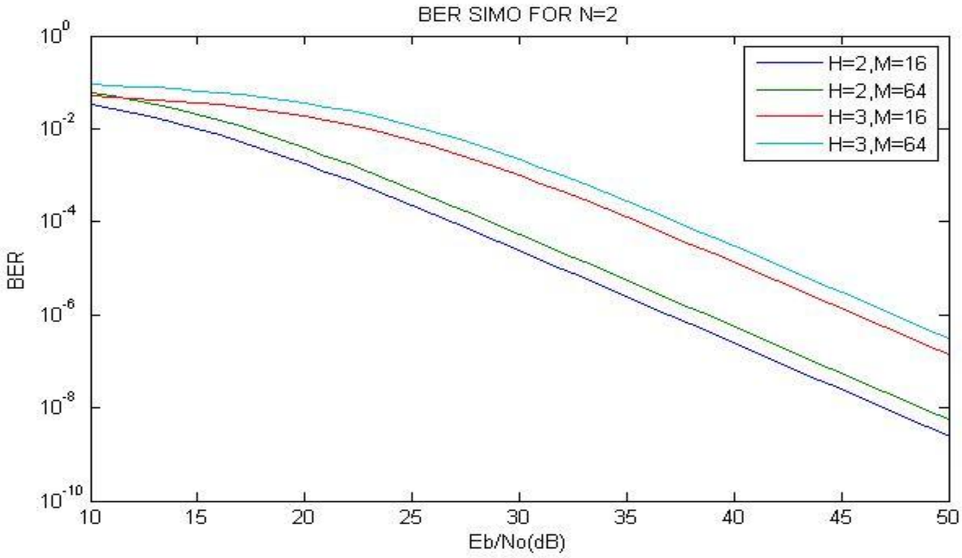

Fig 6: BER SIMO system for N=2

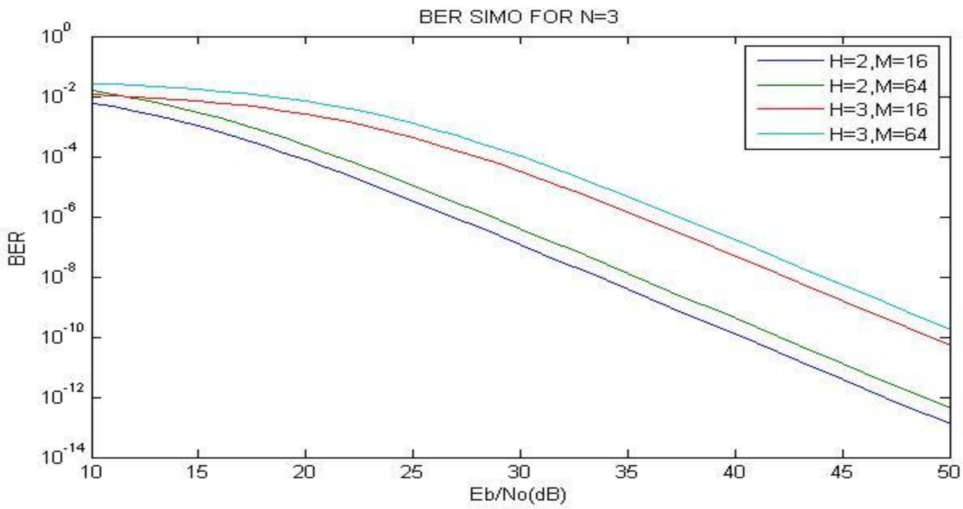

Fig 7: BER SIMO system for N=3

As it is concluded by comparison of figures 6 and 7, as the number of the receivers increases, the BER of the system decreases due to the fact that all the receivers cooperate in order to enhance the received signal and also each receiver has the same γ with the other. In addition to this, in each figure it is obvious that the more hops and M the system has, the larger BER occurs.

On the other hand, the SS process is proved an effective way of signal transmission with lower BER. Forward Error Correction (FEC) employed as a Convolution coding is also productive in obtaining a lowered BER thus reducing the inherent disadvantage of a QAM system i.e. high SNR requirement for a small change in BER[19].

In order to enhance the system performance and avoid the appearance of errors during the transmission of the signal, various error coding techniques can be used such as [20]:

- TPC.
- Serially Concatenated Convolutional Code (SCCC).
- Standard Convolutional Code (SCC).

Comparison of these techniques proves that, the most effective technique is the SCCC because it enhances the Bit Error Probability (BEP) in many orders of magnitude for high values of SNR for frequency hop communication systems operating over an Additive White Gaussian Noise (AWGN) channel and the Log Likelihood Ratio (LLR) metric. For instance, for SNR=4dB the BEP for SCCC is approximately equal to 0.5, for TPC is equal to 10^{-1} and for SCC is equal to $8*10^{-2}$. However, for SNR≥5dB the SCCC has the best performance because its BEP=0, while the TPC has BEP=$8*10^{-5}$ and the SCC has BEP=10^{-2} (where it is equal to 0 for SNR=8.3dB).

6. Conclusion

In this project, a wireless RF communication system using UAS was described to mitigate the multipath effect that occurs while two or more ships are trying to communicate on an archipelagos environment. Implementing the UAS as relay nodes, it is achieved a better LOS coverage of a region overcoming the possible physical obstacles that may occur. Also, using the abovementioned multiplexing and modulation techniques, the QoS augmentation of the system is achieved. In future work, the whole proposed system will be tested in the region of the physical layer taking into consideration different values of fading and noise factors, such as the sea clutter and the precipitation.

References

1. Advances in Massive MIMO Antenna Design, Channel Modeling, and System Technologies

2. Zander &Malmgren, 1995.

3. Sethy, Niharika and Subhakanta Swain. “BER analysis of MIMO-OFDM system in different fading channel.” (2013).

4. M. K. Samimi, S. Sun and T. S. Rappaport, "MIMO channel modeling and capacity analysis for 5G millimeter-wave wireless systems," *2016 10th European Conference on Antennas and Propagation (EuCAP)*, Davos, 2016, pp.1-5.
doi: 10.1109/EuCAP.2016.7481507

ISSN:1791-4469

5. J. Reig and L. Rubio, "Estimation of the Composite Fast Fading and Shadowing Distribution Using the Log-Moments in Wireless Communications," in *IEEE Transactions on Wireless Communications*, vol. 12, no. 8, pp. 3672-3681, August 2013. doi: 10.1109/TWC.2013.050713.120054

6. Yuan-Pei Lin and See-May Phoong, "BER minimized OFDM systems with channel independent precoders," in *IEEE Transactions on Signal Processing*, vol. 51, no. 9, pp. 2369-2380, Sept. 2003. doi: 10.1109/TSP.2003.815391

7. L. Rugini and P. Banelli, "BER of OFDM systems impaired by carrier frequency offset in multipath fading channels," in *IEEE Transactions on Wireless Communications*, vol. 4, no. 5, pp. 2279-2288, Sept. 2005.
doi: 10.1109/TWC.2005.853884

8. J. Akella, M. Yuksel and S. Kalyanaraman, "Error analysis of multi-hop free-space optical communication," *IEEE International Conference on Communications, 2005.ICC 2005.2005*, Seoul, 2005, pp.1777-1781 Vol. 3.
doi: 10.1109/ICC.2005.1494647

9. P. Podder, T. Zaman Khan, M. Haque Khan, M. Muktadir, “BER Performance Analysis of OFDM-BPSK, QPSK, QAM Over Rayleigh Fading Channel & AWGN Channel” International Journal of Industrial Electronics and Electrical Engineering, ISSN: 2347-6982, Volume-2, Issue-7, July-2014.

10. M. Meena, M. Singh, “Performance Analysis of BER with FHSS System”, Volume II, Issue V, May 2013, IJLTEMAS, ISSN 2278 – 2540, pgs. 29-35.

11. E. Morgado, I. Mora-Jiménez, J.J. Vinagre, J. Ramos, A. J. Caamano, “End-to-End Average BER in Multihop Wireless Networks over Fading Channels”, IEEE TRANSACTIONS ON WIRELESS COMMUNICATIONS, VOL. 9, NO. 8, AUGUST 2010, pgs. 2478-2487.

12. N. Jindal, J. G. Andrews and S. Weber, "Multi-Antenna Communication in Ad Hoc Networks: Achieving MIMO Gains with SIMO Transmission," in *IEEE Transactions on Communications*, vol. 59, no. 2, pp. 529-540, February 2011.
doi: 10.1109/TCOMM.2010.120710.090793

13. G.K. Varotsos, H.E. Nistazakis, M.I. Petkovic, G.T. Djordjevic, G.S. Tombras, “SIMO optical wireless links with nonzero boresight pointing errors over M modeled turbulence channels”, Optics Communications, Volume 403, 2017, Pages 391-400, ISSN 0030-4018, https://doi.org/10.1016/j.optcom.2017.07.055.

14. A Flexible Phased-MIMO Array Antenna with Transmit Beamforming

15. Beamforming Techniques for Wireless MIMO Relay Networks

16. H.E. Nistazakis, A.N. Stassinakis, S. Sheikh Muhammad, G.S. Tombras, “BER estimation for multi-hop RoFSO QAM or PSK OFDM communication systems over gamma gamma or exponentially modeled turbulence channels”, Optics & Laser Technology, Volume 64, 2014, Pages 106-112, ISSN 0030-3992, https://doi.org/10.1016/j.optlastec.2014.05.004.

17. K.N. Manganaris, N.A. Androutsos, A.N. Stassinakis, A.D. Tsigopoulos, A. Tzanakaki, H.E. Nistazakis, “Outage performance study of a multi-hop AF relay system approximated by a dual-hop scheme over Rician fading wireless channels”, pgs. 281-286, 8th International Conference on “Experiments/Process/System Modeling/Simulation/Optimization” 8th IC-EPSMSO,Athens 3-6 July 2019, ©LFME.

18. Yuan, Y., Chen, M. & Kwon, T, “A Novel Cluster-Based Cooperative MIMO Scheme for Multi-Hop Wireless Sensor Networks”, *J. Wireless Com Network* **2006,** 072493 (2006). https://doi.org/10.1155/WCN/2006/72493.

19. B. Sklar “Rayleigh Fading Channels” Mobile Communications Handbook Ed. Suthan S. Suthersan Boca Raton: CRC Press LLC, 1999.

20. H. S. Kim and B. Daneshrad, "Energy-Constrained Link Adaptation for MIMO OFDM Wireless Communication Systems," in *IEEE Transactions on Wireless Communications*, vol. 9, no. 9, pp. 2820-2832, September 2010.
doi: 10.1109/TWC.2010.062910.090983.

21. H. E. Nistazakis, A. N. Stassinakis, H. G. Sandalidis and G. S. Tombras, "QAM and PSK OFDM RoFSO Over M-Turbulence Induced Fading Channels," in *IEEE Photonics Journal*, vol. 7, no. 1, pp. 1-11, Feb. 2015, Art no. 7900411.
doi: 10.1109/JPHOT.2014.2381670

22. B. Ahmed, M. Abdul Matin, “Coding for MIMO-OFDM in Future Wireless Systems”, Springer Cham Heidelberg New York Dordrecht London, ISSN 2191-8120 (electronic) Springer Briefs in Electrical and Computer Engineering, ISBN 978-3-319-19153-9 (eBook) DOI 10.1007/978-3-319-19153-9 © The Author(s) 2015.

23. M. Strasser, C. Popper, S. Capkun and M. Cagalj, "Jamming-resistant Key Establishment using Uncoordinated Frequency Hopping," *2008 IEEE Symposium on Security and Privacy (sp 2008)*, Oakland, CA, 2008, pp. 64-78.
doi: 10.1109/SP.2008.9

24. C. Chen and P. P. Vaidyanathan, "MIMO Radar Ambiguity Properties and Optimization Using Frequency-Hopping Waveforms," in *IEEE Transactions on Signal Processing*, vol. 56, no. 12, pp. 5926-5936, Dec. 2008.
doi: 10.1109/TSP.2008.929658.

25. N. Hossein Motlagh, “Frequency Hopping Spread Spectrum: An Effective Way to Improve Wireless Communication Performance” pgs. 187-202, Advanced Trends in Wireless Communications.

26. W.G. Phoe, J.A. Pursley, M.B. Pursley, J.S. Skinner, “FREQUENCY-HOP SPREAD SPECTRUM WITH QUADRATURE AMPLITUDE MODULATION AND ERROR-CONTROL CODING”, MILCOM 2004 - 2004 IEEE Military Communications Conference, pgs. 913-919.

27. A.N. Stassinakis, H.E. Nistazakis, G.S. Tombras "Comparative performance study of one or multiple receivers schemes for FSO links over gamma–gamma turbulence channels", Journal of Modern Optics Vol. 59, No. 11, 20 June 2012, pgs. 1023–1031.